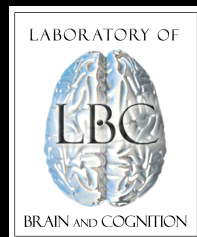


Brain Reading with fMRI

07.31.13

Chris Baker

Laboratory of Brain and Cognition, NIMH

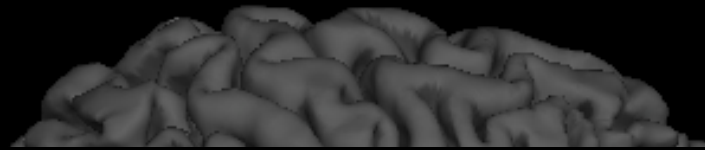


I Saw That on TV.....

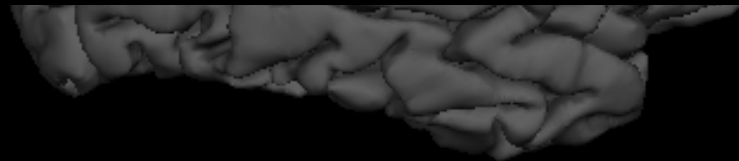
CBS – 60 Minutes, 2009

“mind reading”

“thought identification”



What can we really do?



“prediction”

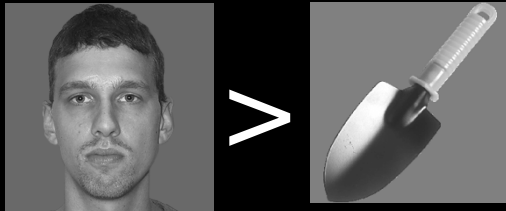
“decoding”

Let's Read Some Brains

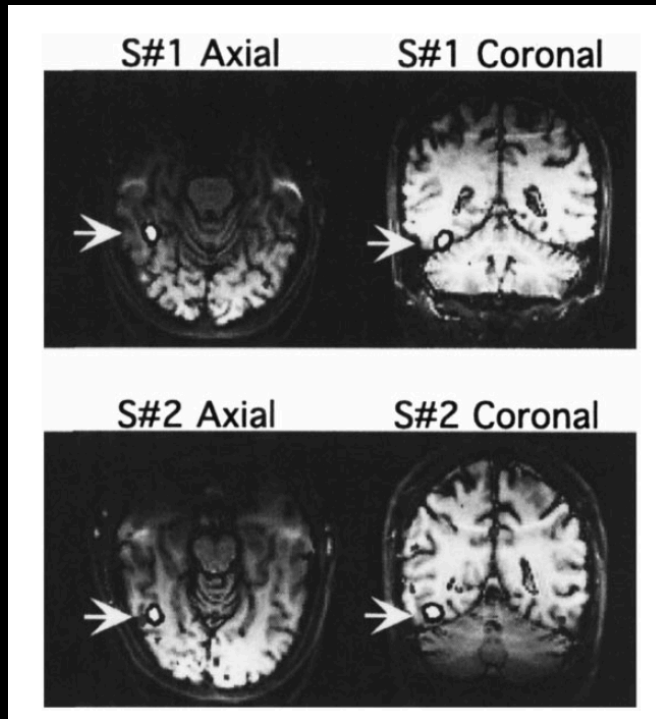
- 1) Training
- 2) Test

I) Training

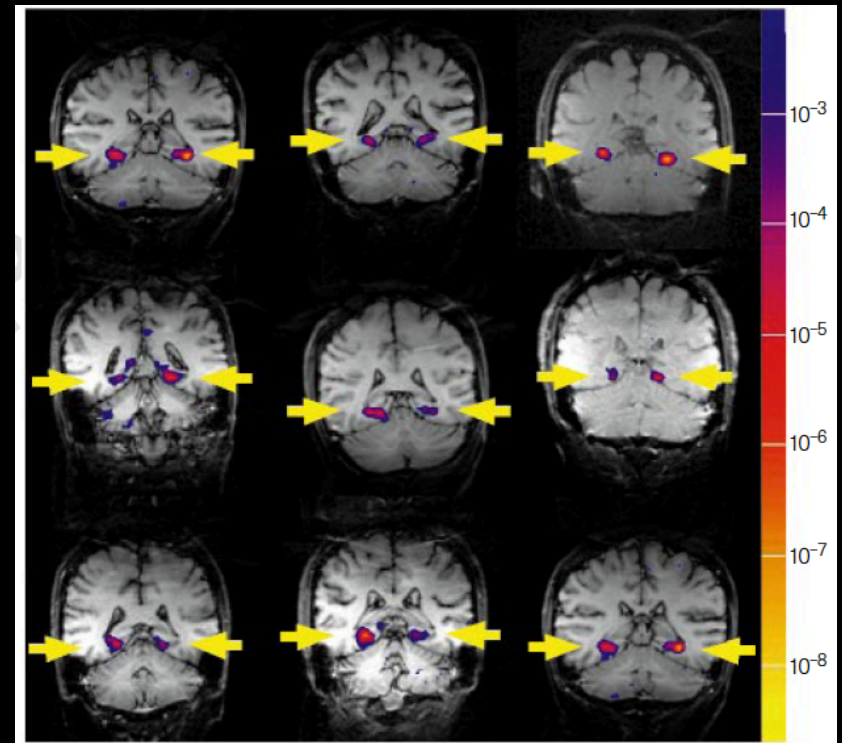
Face-selective cortex
(Fusiform Face Area, FFA)



Scene-selective cortex
(Parahippocampal Place Area, PPA)

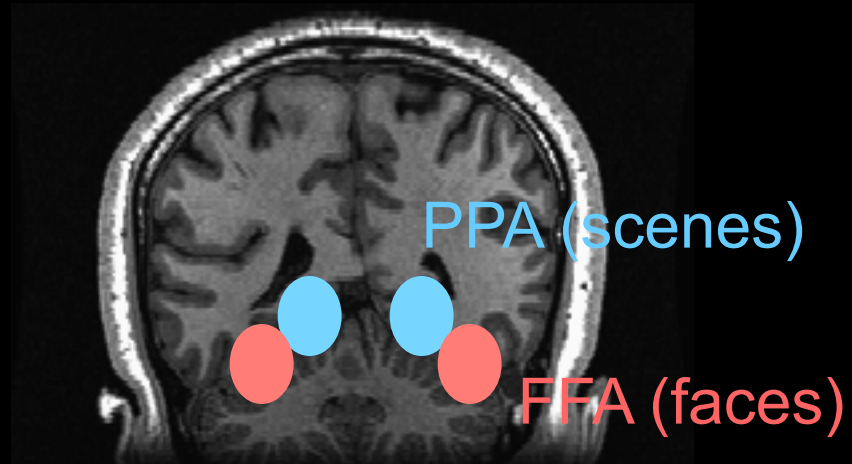


Kanwisher et al. (1997). *J. Neurosci.*, 17, 4302-4311



Epstein and Kanwisher (1998). *Nature*, 392, 598-601

I) Training



2) Test

S1



Faces



Scenes

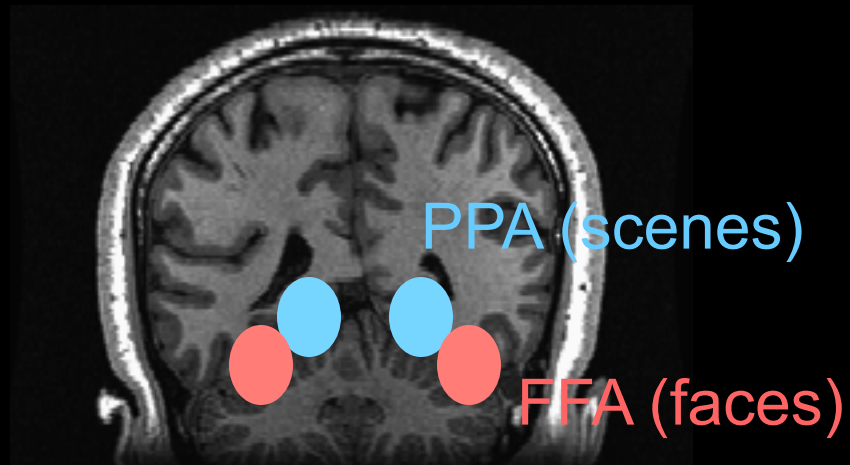
S2



Scenes



Faces



S1



Faces



Scenes

S2



Scenes



Faces

Brain activity \leftrightarrow Stimulus

- Decoding models
 - Uses voxel activity to predict stimulus information
- Encoding models
 - Explicit description of how information is represented in activity of single voxels

Brain activity \leftrightarrow Stimulus

- Decoding models
 - Uses voxel activity to predict stimulus information
- Encoding models
 - Explicit description of how information is represented in activity of single voxels

“brain reading”

“classification”



Multi Voxel Pattern Analysis (MVPA)

“prediction”

“decoding”

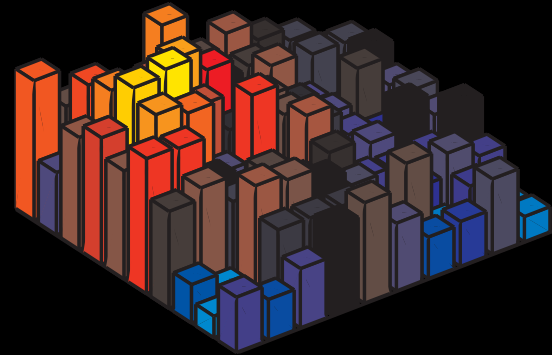
Univariate vs. Multivariate

- Classic fMRI analyses = univariate
 - Each voxel considered independently
- Multivariate
 - Responses of voxels considered jointly
 - Pattern of response

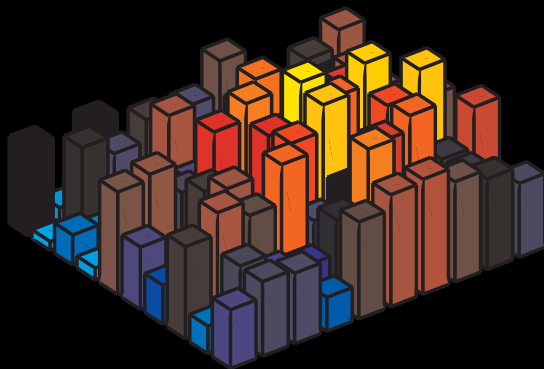
Condition 1



Condition 2



Condition 3



Condition n



Voxel 2

Condition A

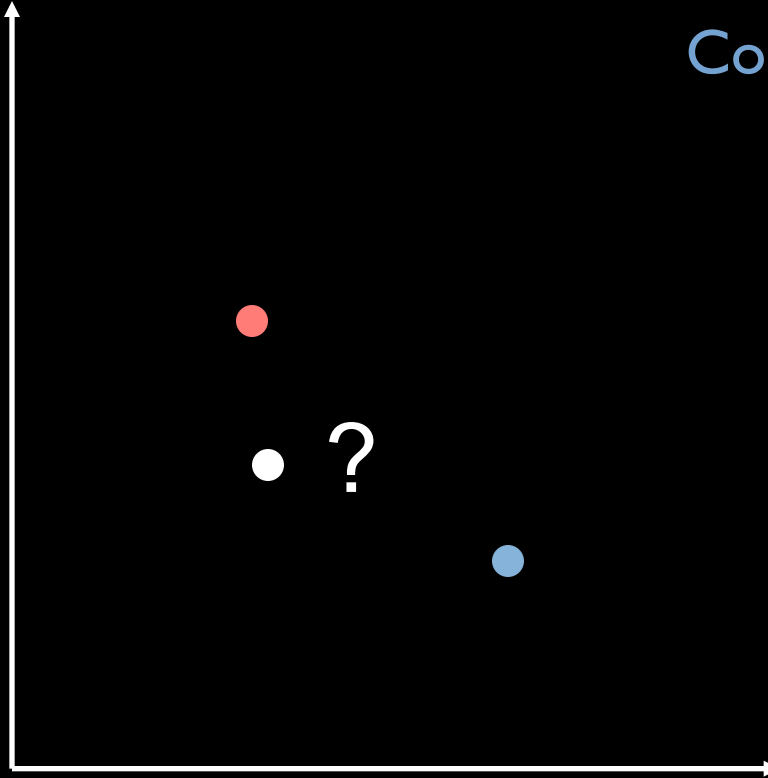
Condition B



?



Voxel 1

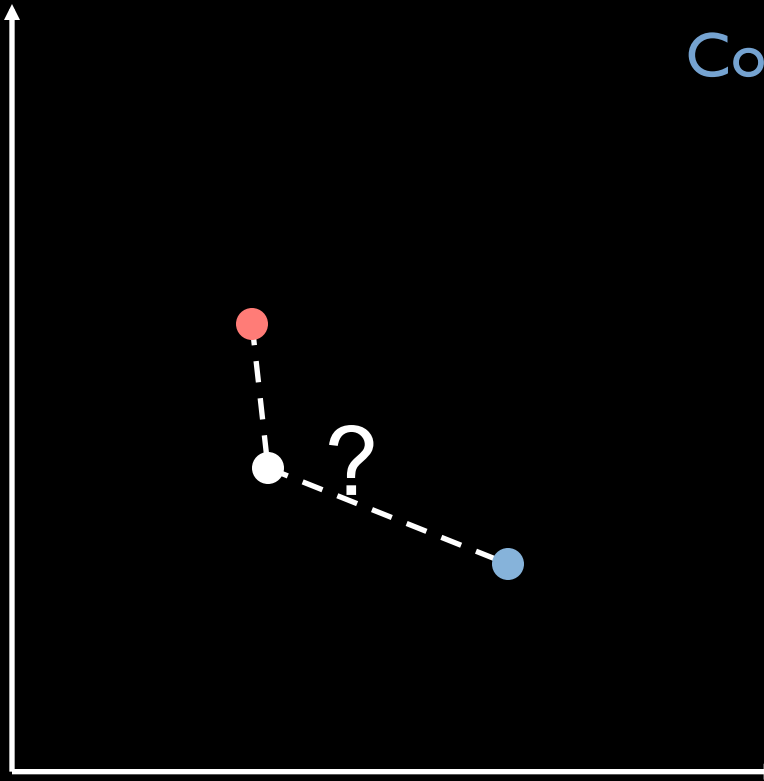


Euclidean Distance

Voxel 2

Condition A

Condition B



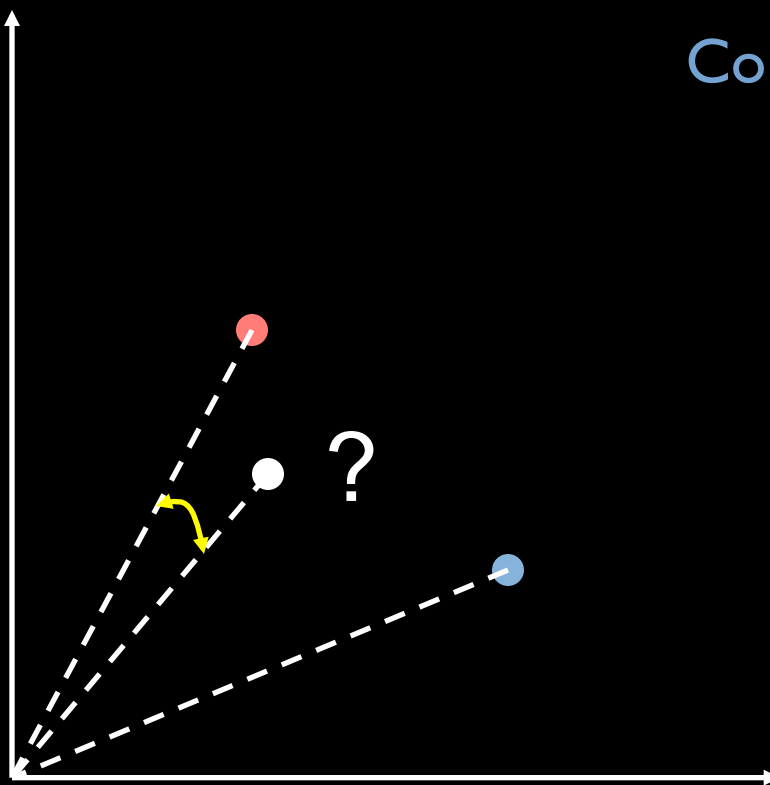
Voxel 1

Correlation

Voxel 2

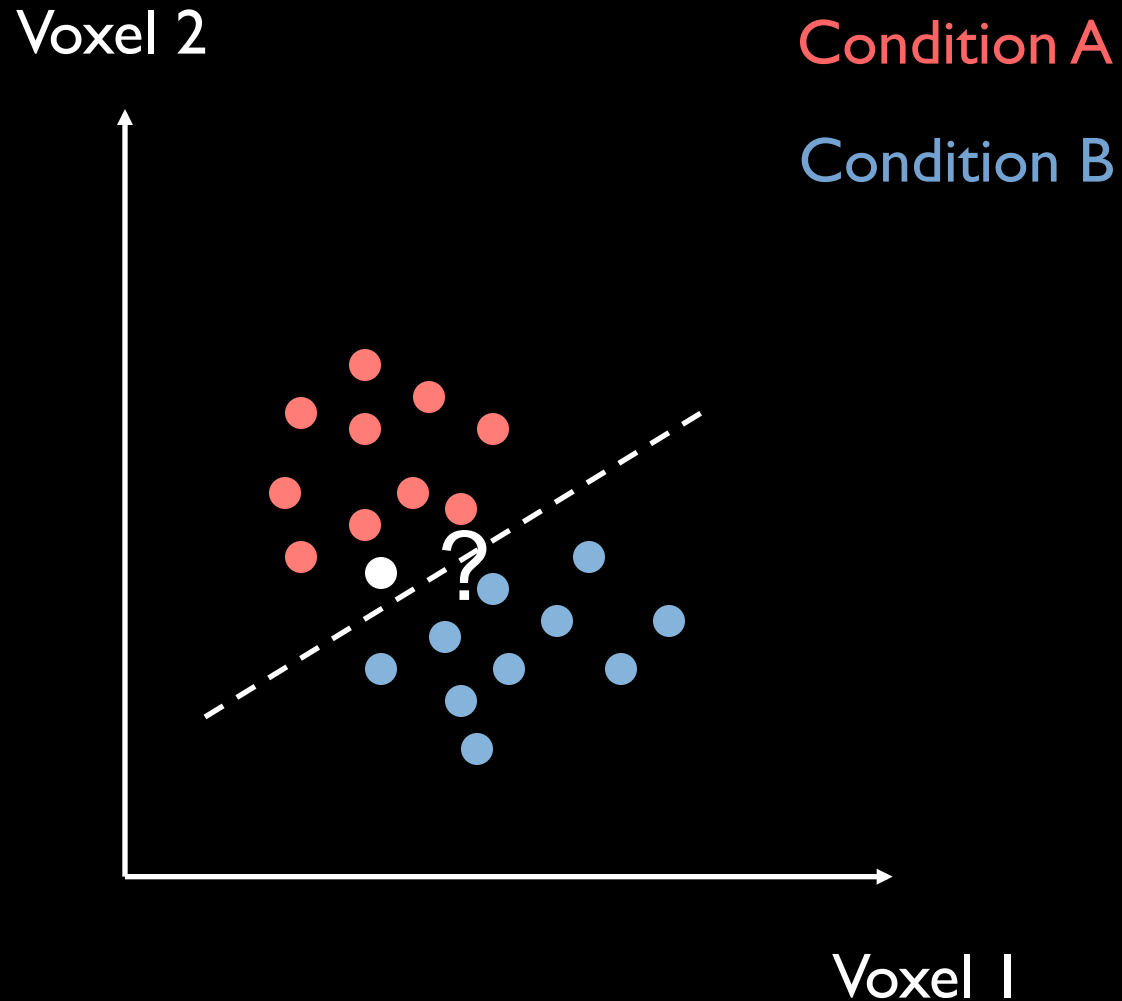
Condition A

Condition B



Voxel 1

Support Vector Machine (SVM)



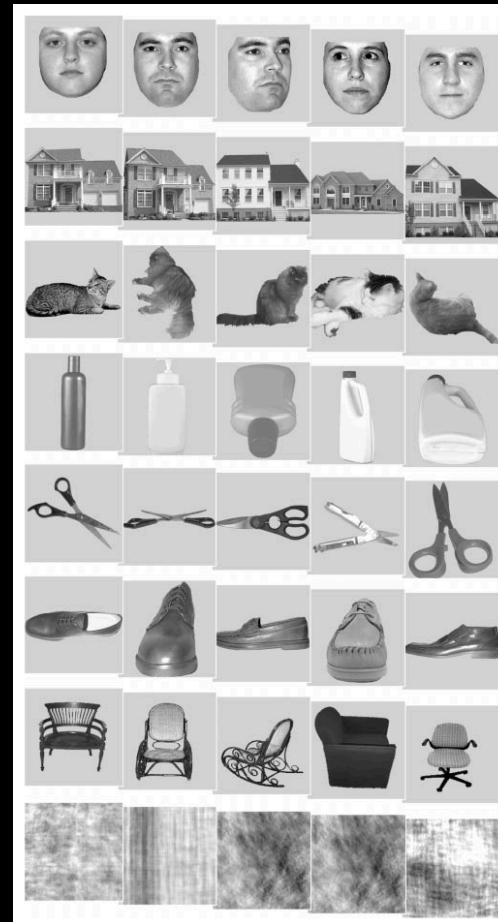
Linear Classifiers

- Euclidean distance
- Correlation
- Linear SVM
- Fisher Least Discriminant Analysis
- Neural networks (without hidden layer)
- Gaussian Naïve Bayes Classifiers

Non-linear classifiers increase risk of overfitting

Object representations in ventral temporal cortex (Haxby et al, 2001)

- Participants viewed blocks of images from 8 categories
- I-back task
- Split-half correlation analysis



Correlation

Voxel 2

Condition A

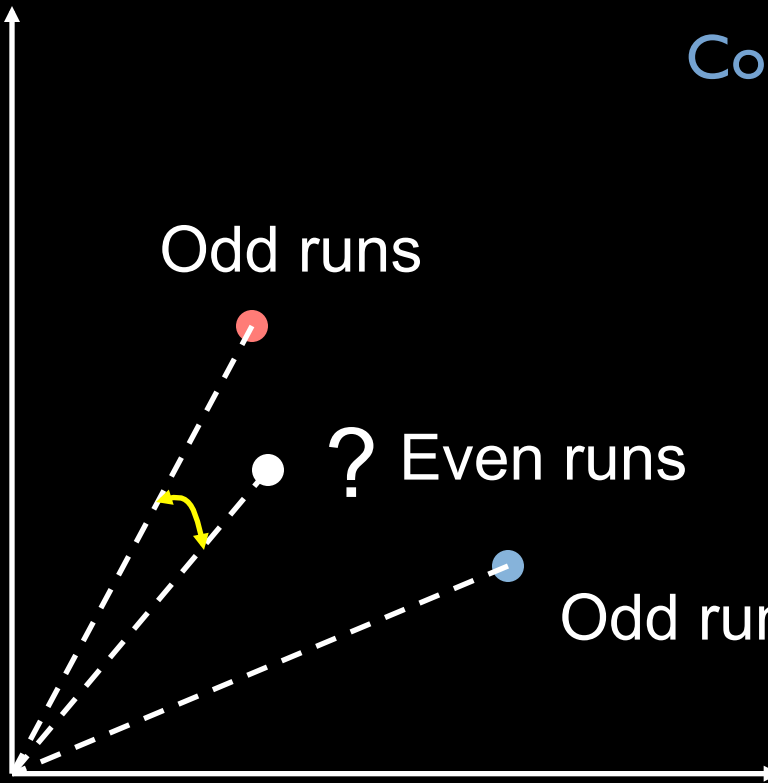
Condition B

Odd runs

? Even runs

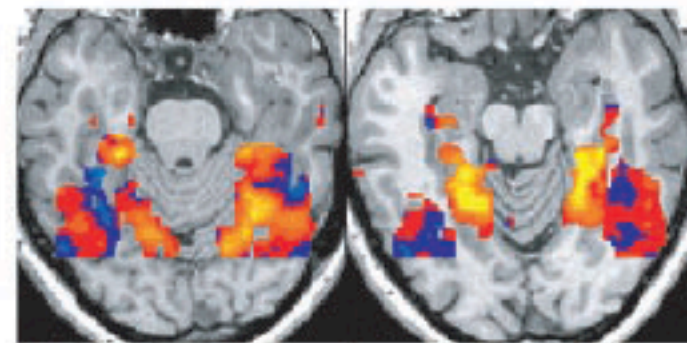
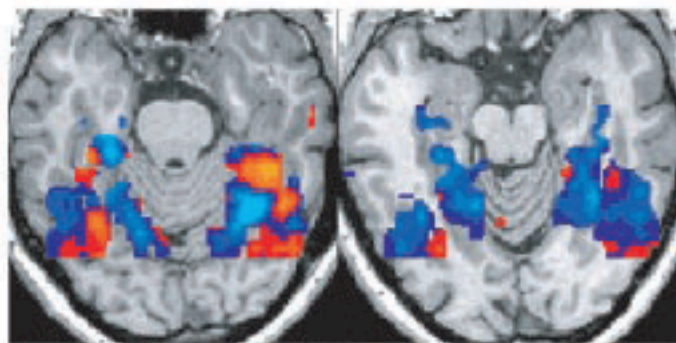
Odd runs

Voxel 1



A

Even
Runs



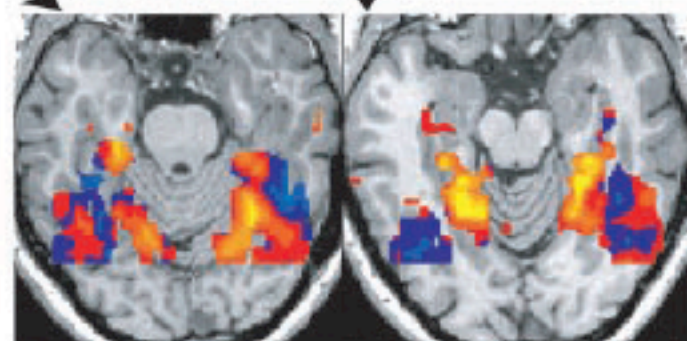
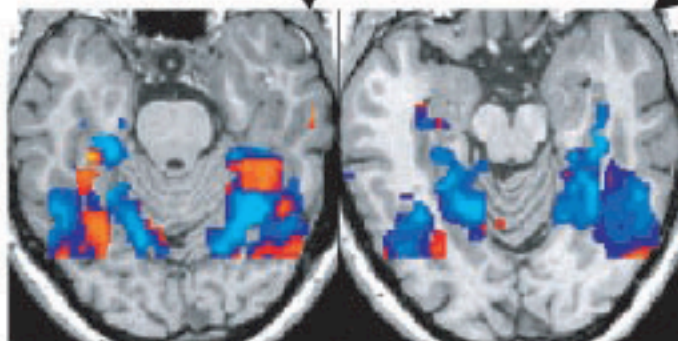
$r = 0.81$

$r = -0.40$

$r = -0.47$

$r = 0.87$

Odd
Runs



Response
to Faces

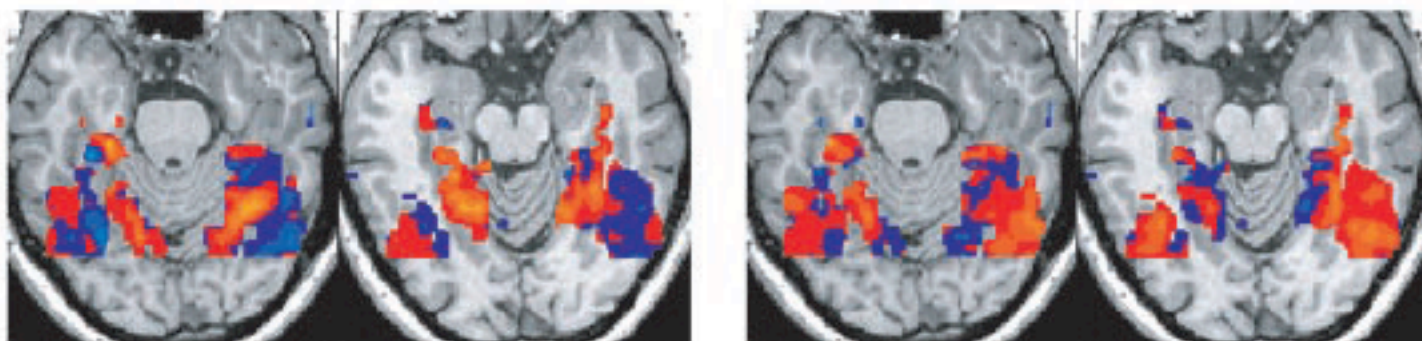


Response
to Houses



B

Even
Runs



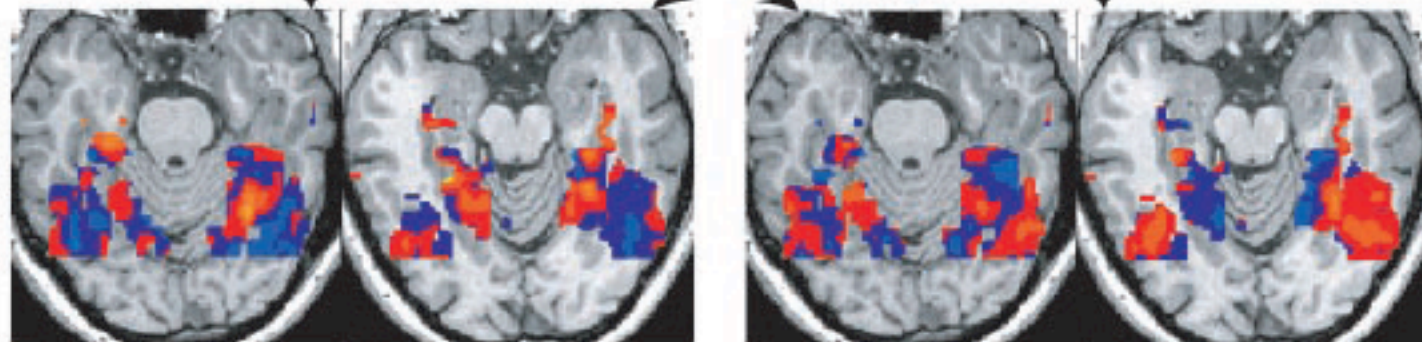
$r = 0.45$

$r = -0.12$

$r = -0.10$

$r = 0.55$

Odd
Runs



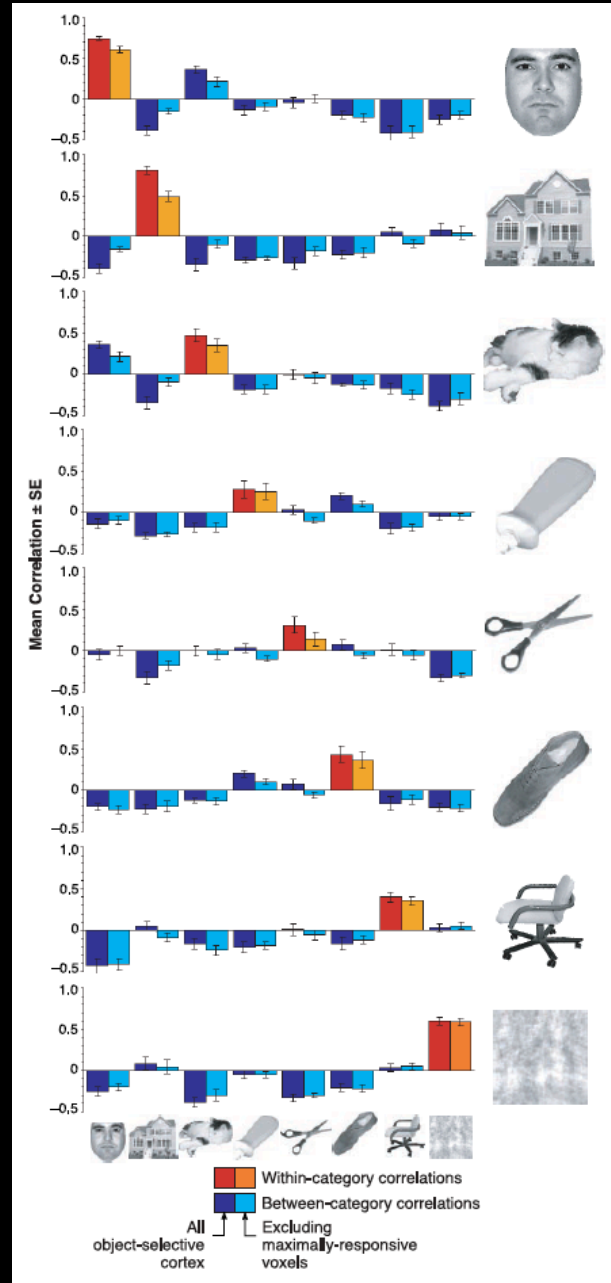
Response
to Chairs



Response
to Shoes



Higher within- than
between-category
correlations



Decoding Accuracy

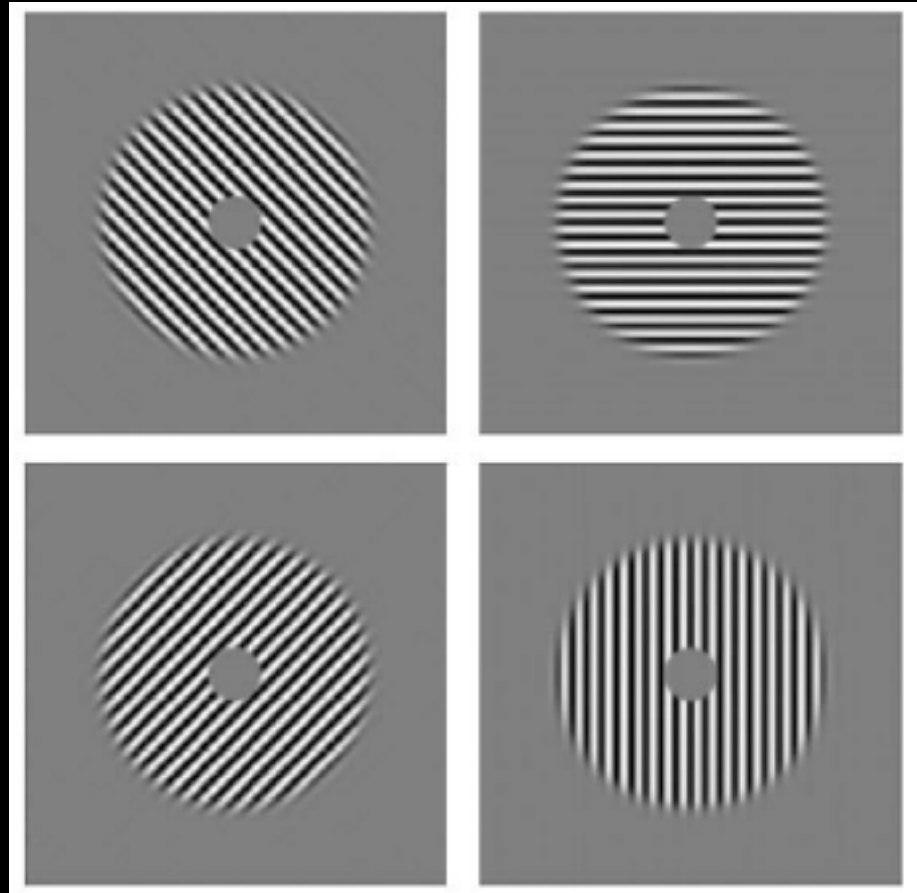
Table 1. Accuracy of identification of the category being viewed based on the patterns of response evoked in ventral temporal cortex. Accuracies are the percentage of comparisons between two categories that correctly identified which category was being viewed.

Region	Volume (cm ³ ± SE)	Identification accuracy (%)							
		Faces	Houses	Cats	Bottles	Scissors	Shoes	Chairs	Scrambled
All ventral temporal object-selective cortex	22.9 ± 2.8	100***	100***	98 ± 2***	90 ± 6***	92 ± 6***	92 ± 7***	96 ± 2***	100***
Minus regions that were maximally responsive to categories being compared	15.4 ± 1.8	100***	100***	95 ± 2***	89 ± 6***	85 ± 9**	90 ± 8**	98 ± 1***	100***
Regions maximally responsive to:									
Faces	3.1 ± 0.9	94 ± 7***	99 ± 1***	76 ± 13*	81 ± 14*	77 ± 9*	70 ± 16	77 ± 11*	92 ± 7***
Houses	9.6 ± 1.8	100***	100***	88 ± 5***	85 ± 10**	81 ± 6**	96 ± 2***	94 ± 3***	100***
Cats	2.6 ± 0.4	96 ± 4***	96 ± 2***	82 ± 8**	65 ± 11	69 ± 5**	76 ± 9*	95 ± 4***	100***
Small objects	6.9 ± 1.1	100***	100***	95 ± 3***	83 ± 7**	92 ± 8**	94 ± 6***	90 ± 6***	96 ± 4***

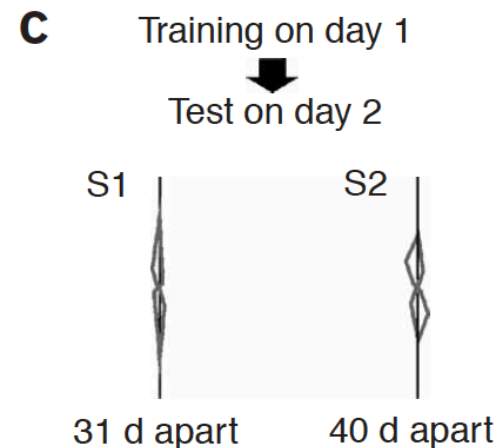
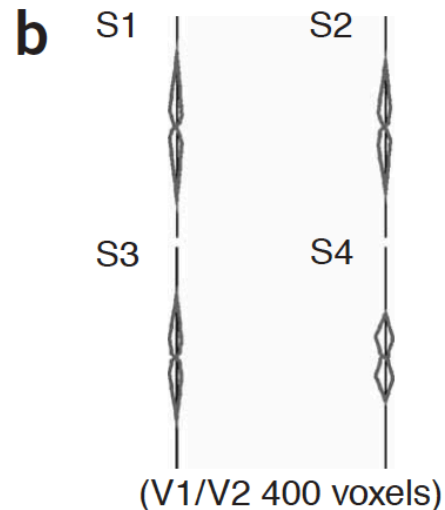
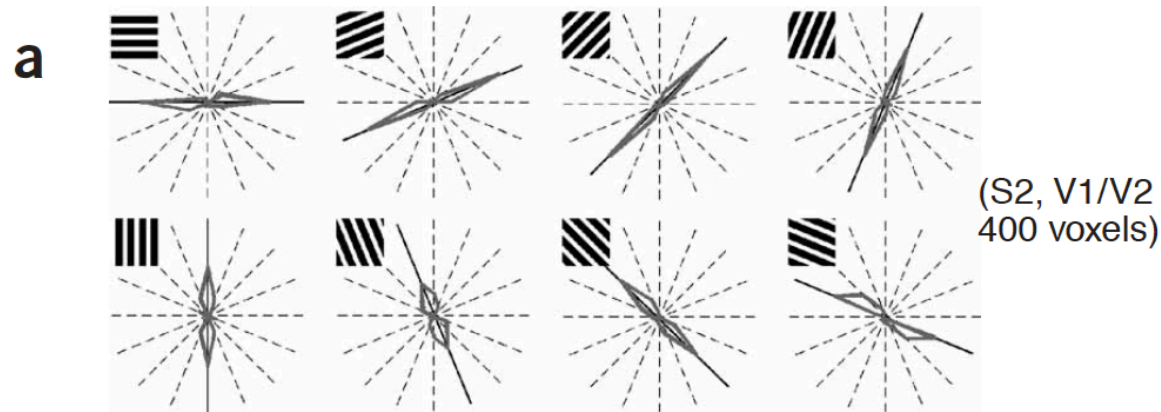
Differs from chance (50%): *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

Decoding Orientation in Early Visual Cortex (Kamitani and Tong, 2005)

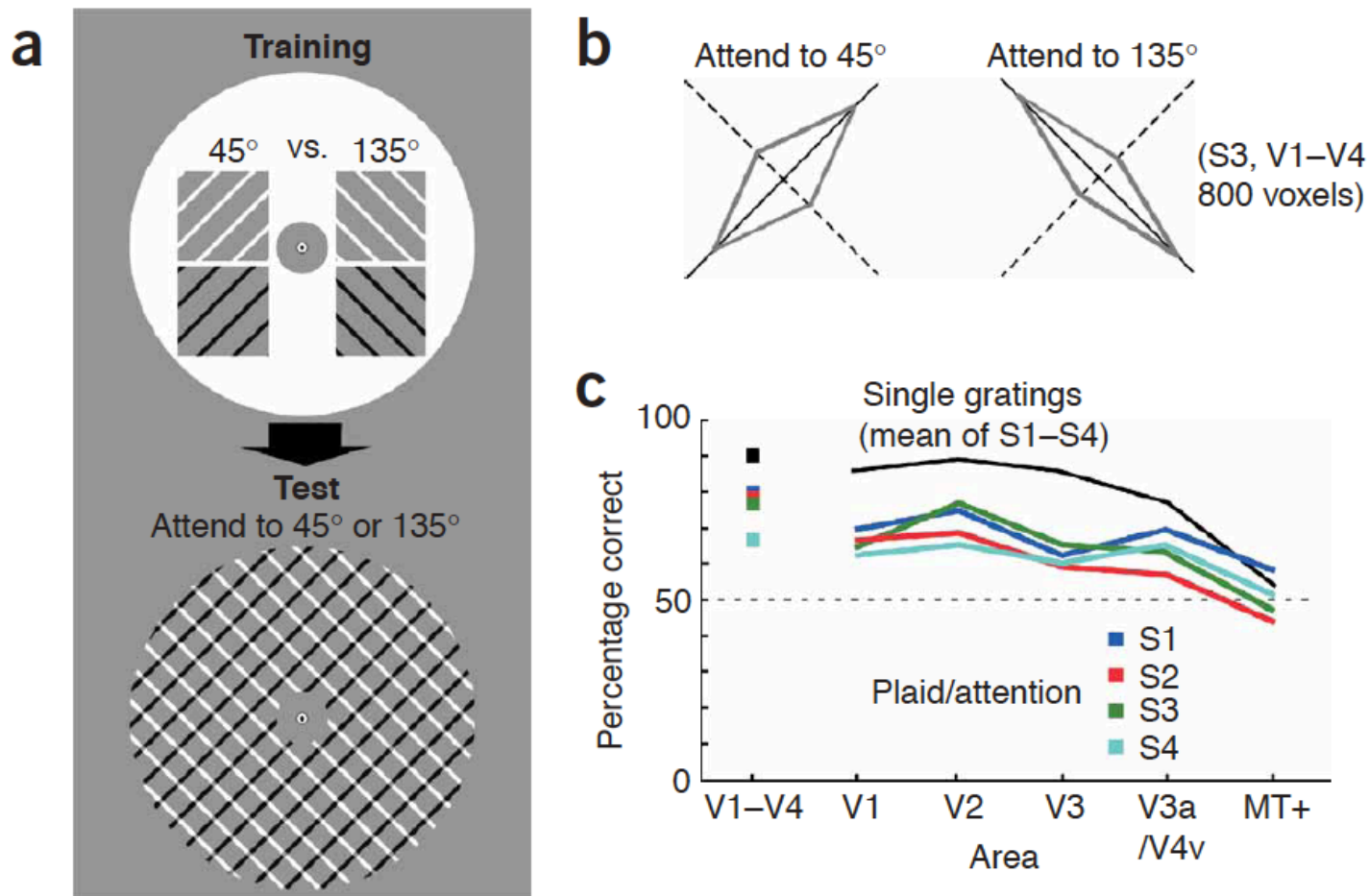
- Participants viewed blocks of oriented lines (8 possible orientations)
- Linear SVM



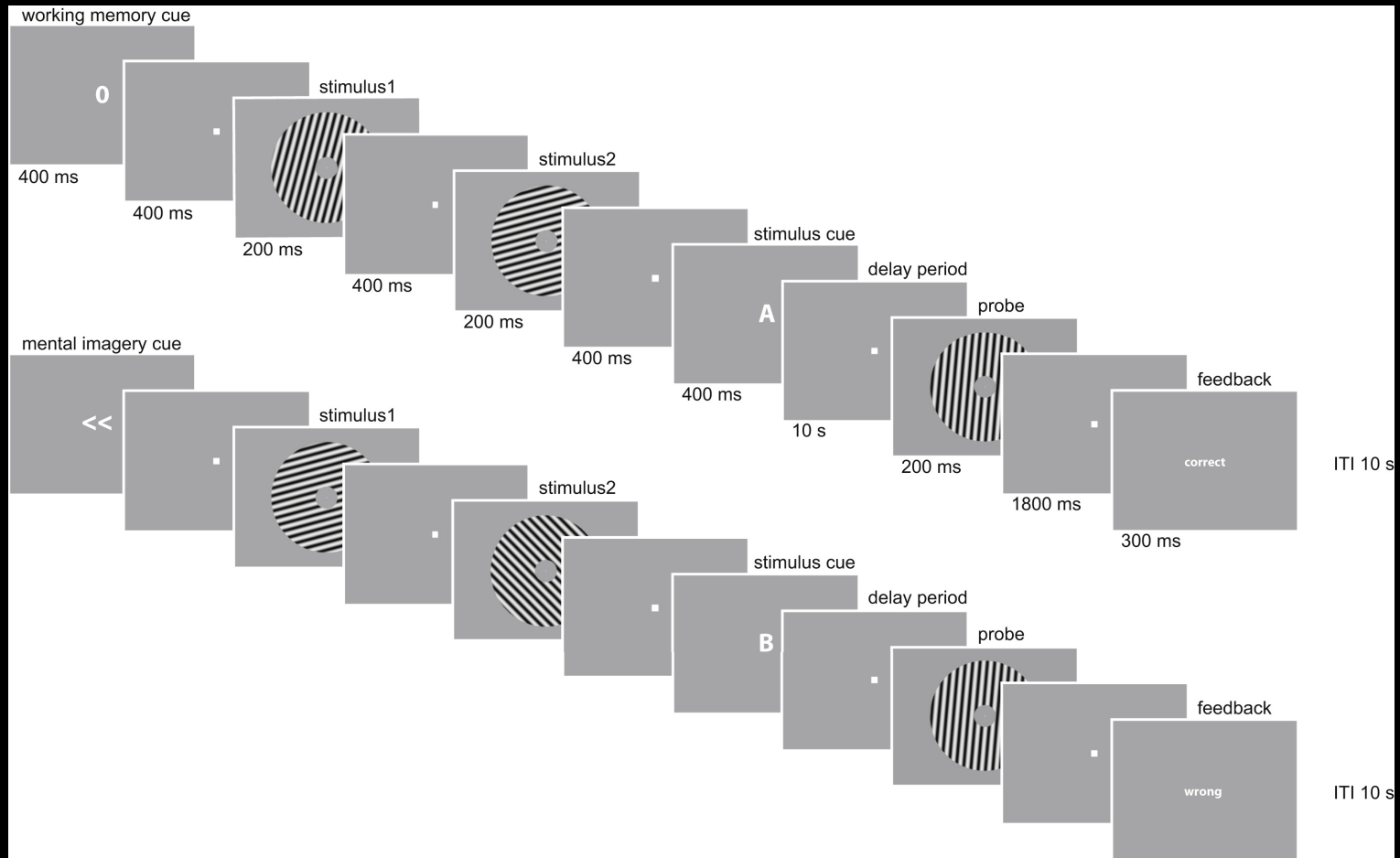
Highly accurate decoding of orientation



Decoding Attended Orientation

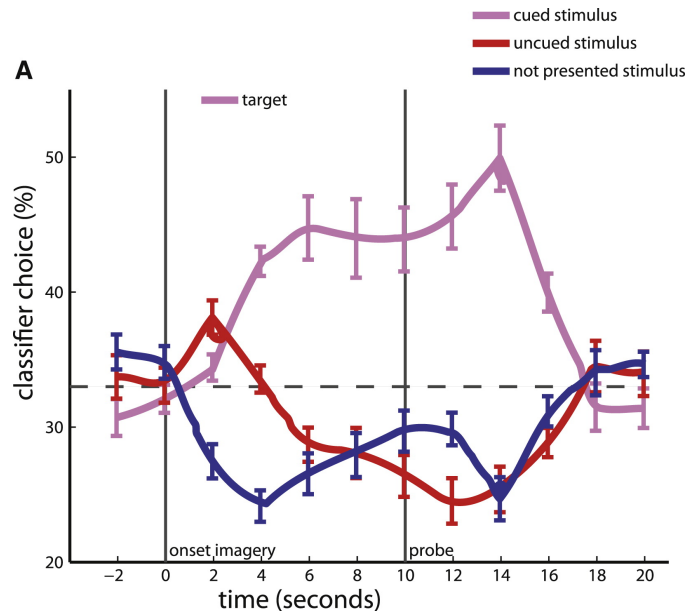


Perception, working memory and imagery (Albers et al, 2013)

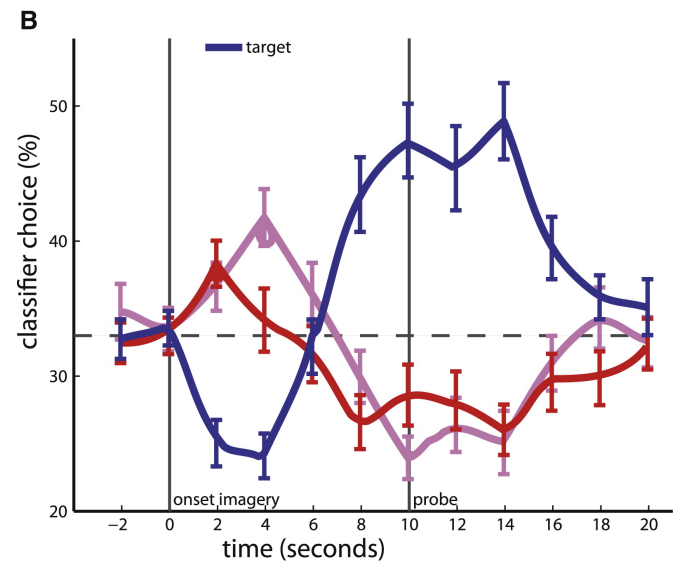


Decoding of mental images

Working Memory



Imagery



Decoding across working memory, imagery and perception

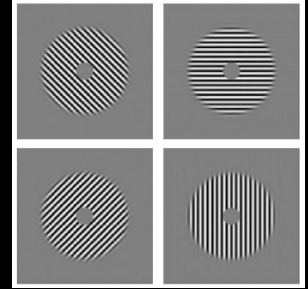
Table S1. Decoding Accuracies for the Different Classifiers in V1, V2, V3, and V1-V3

Area	Decoding within condition		Decoding across conditions		Decoding based on perception	
	WM-WM	IM-IM	IM-WM	WM-IM	VS-WM	VS-IM
V1	44.6% ^{**}	41.6% ^{**}	41.3% ^{***}	38.7% ^{**}	40.1% ^{**}	43.2% ^{***}
V2	50.8% ^{***}	44.0% ^{**}	43.6% ^{***}	41.7% ^{**}	45.2% ^{***}	46.1% ^{***}
V3	52.4% ^{***}	46.0% ^{**}	44.6% ^{***}	42.5% ^{**}	44.4% ^{***}	46.1% ^{***}
V1-V3	54.2% ^{***}	46.1% ^{**}	45.5% ^{***}	45.2% ^{***}	46.4% ^{***}	48.5% ^{***}

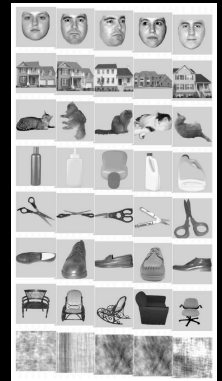
Limitations of Early Decoding Studies

- Restricted stimulus domains
 - Oriented lines
 - Small number of selected categories
- No decoding of novel stimuli or categories
[but see Spiridon and Kanwisher(2002)]

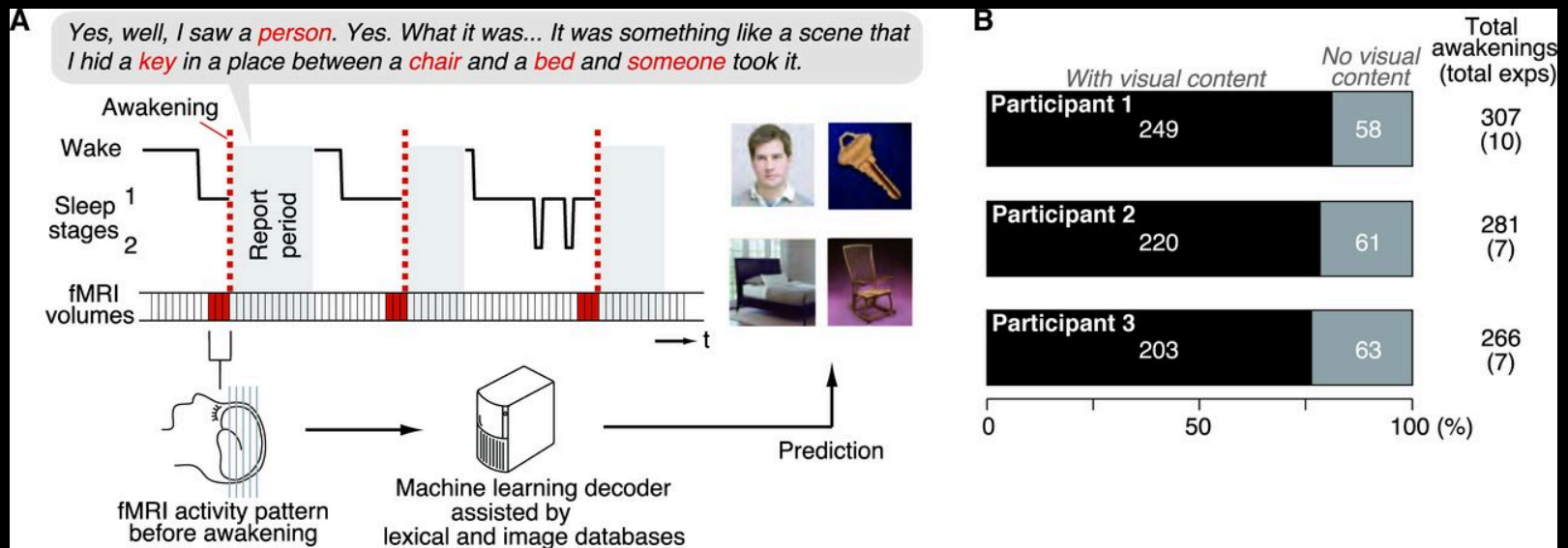
Kamitani and Tong (2005)



Haxby et al (2001)



Decoding Dreams (Horikawa et al, 2013)



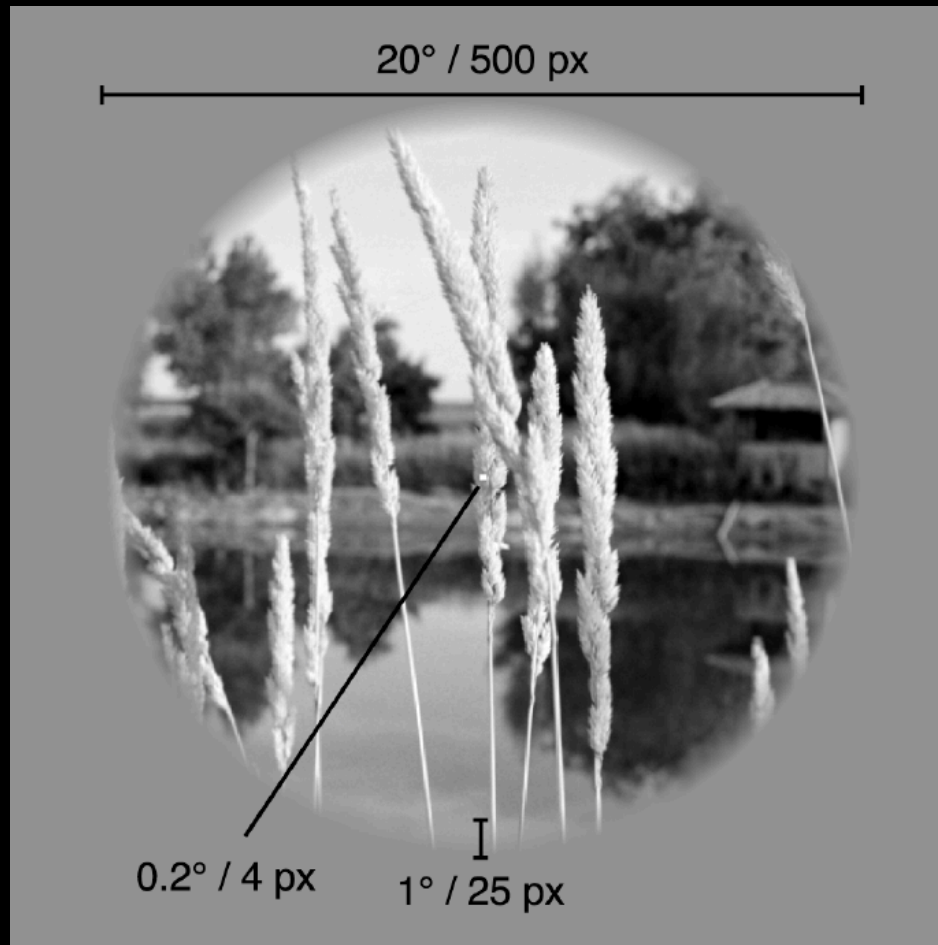
Brain activity \leftrightarrow Stimulus

- Decoding models
 - Uses voxel activity to predict stimulus information
- Encoding models
 - Explicit description of how information is represented in activity of single voxels

Model-based approach to decoding (Kay et al, 2008)

- 1) Characterize relationship between visual stimuli and fMRI activity (i.e. build a model)
 - Complex, natural visual images
 - Early retinotopic visual cortex
- 2) Measure fMRI activity to one of many possible novel images
- 3) Compare actual activity to predicted activity for full set of novel images to determine which image was viewed

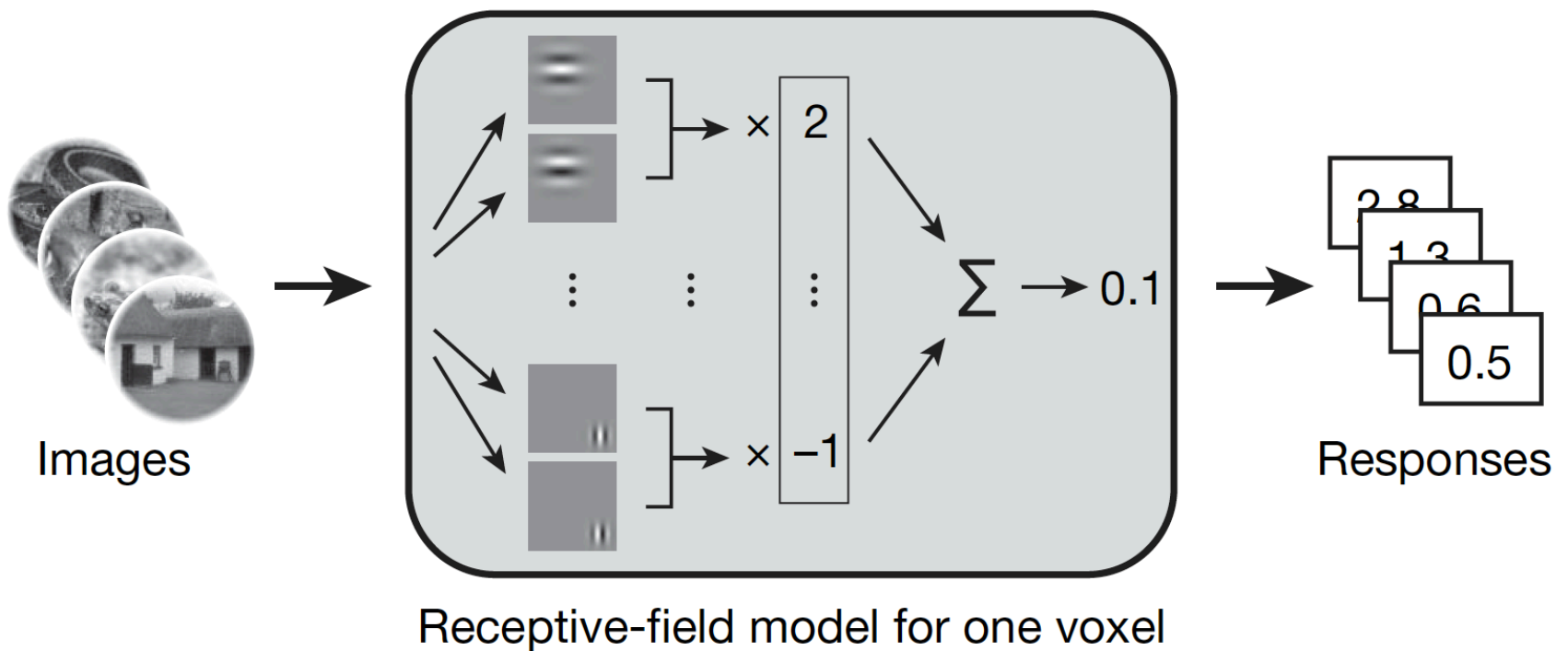
Large gray-scale images



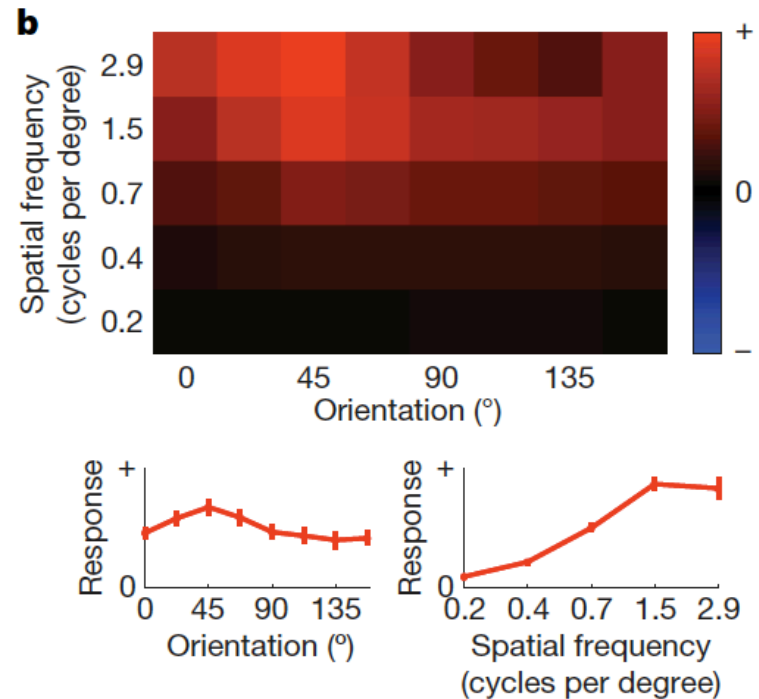
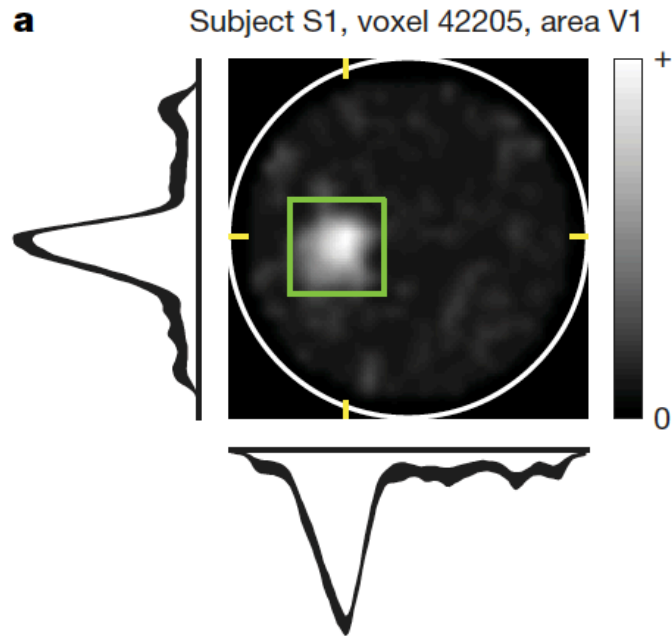
I) Build a Model

Stage 1: model estimation

Estimate a receptive-field model for each voxel



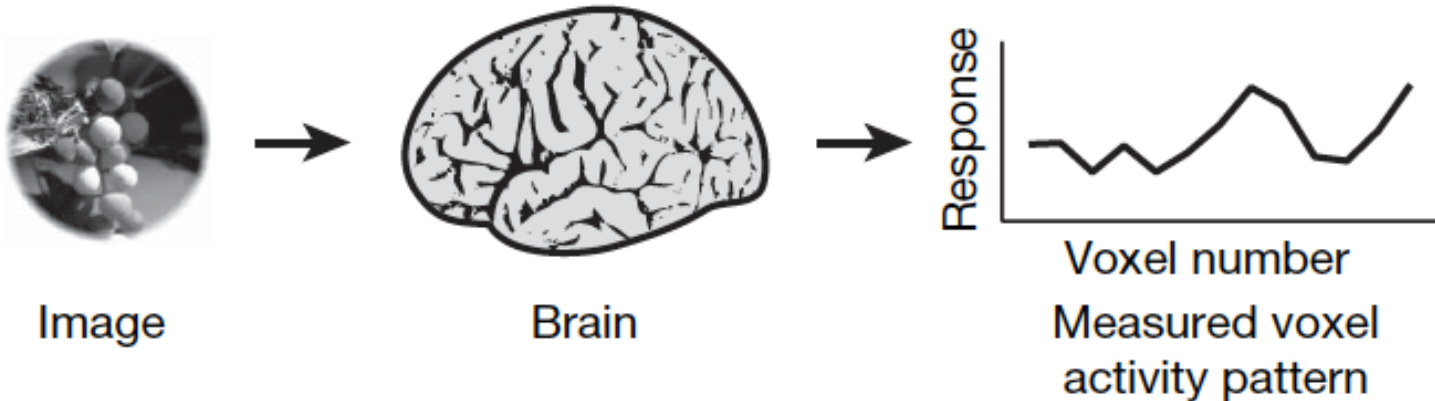
RF model for one voxel



Novel Image to be Identified

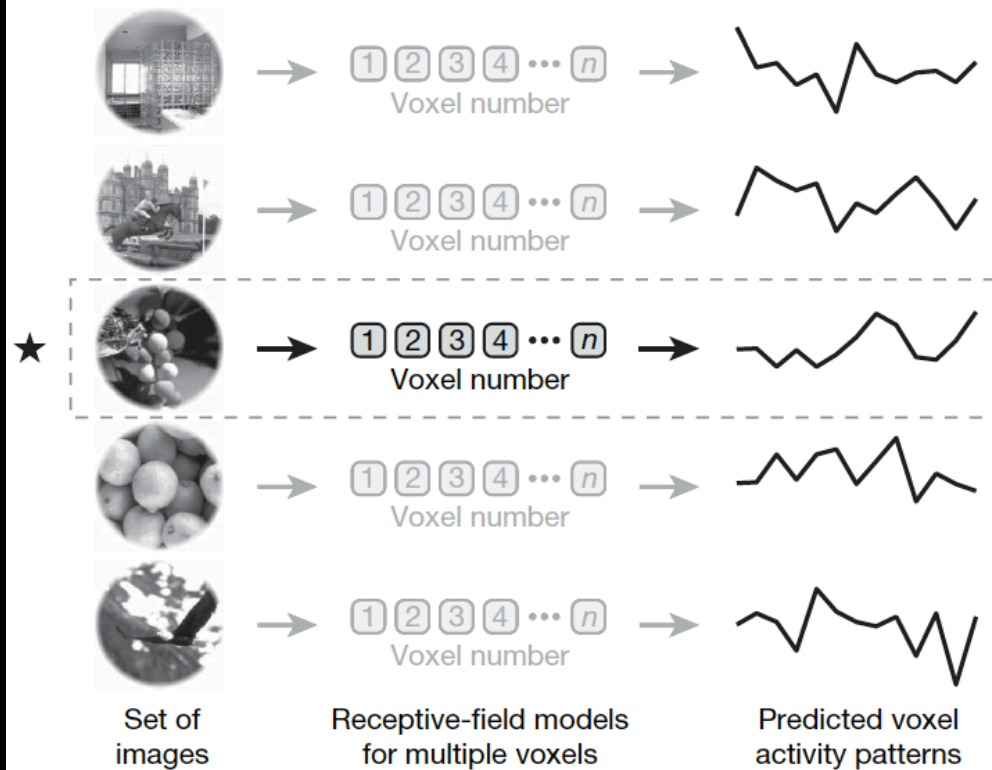
Stage 2: image identification

(1) Measure brain activity for an image



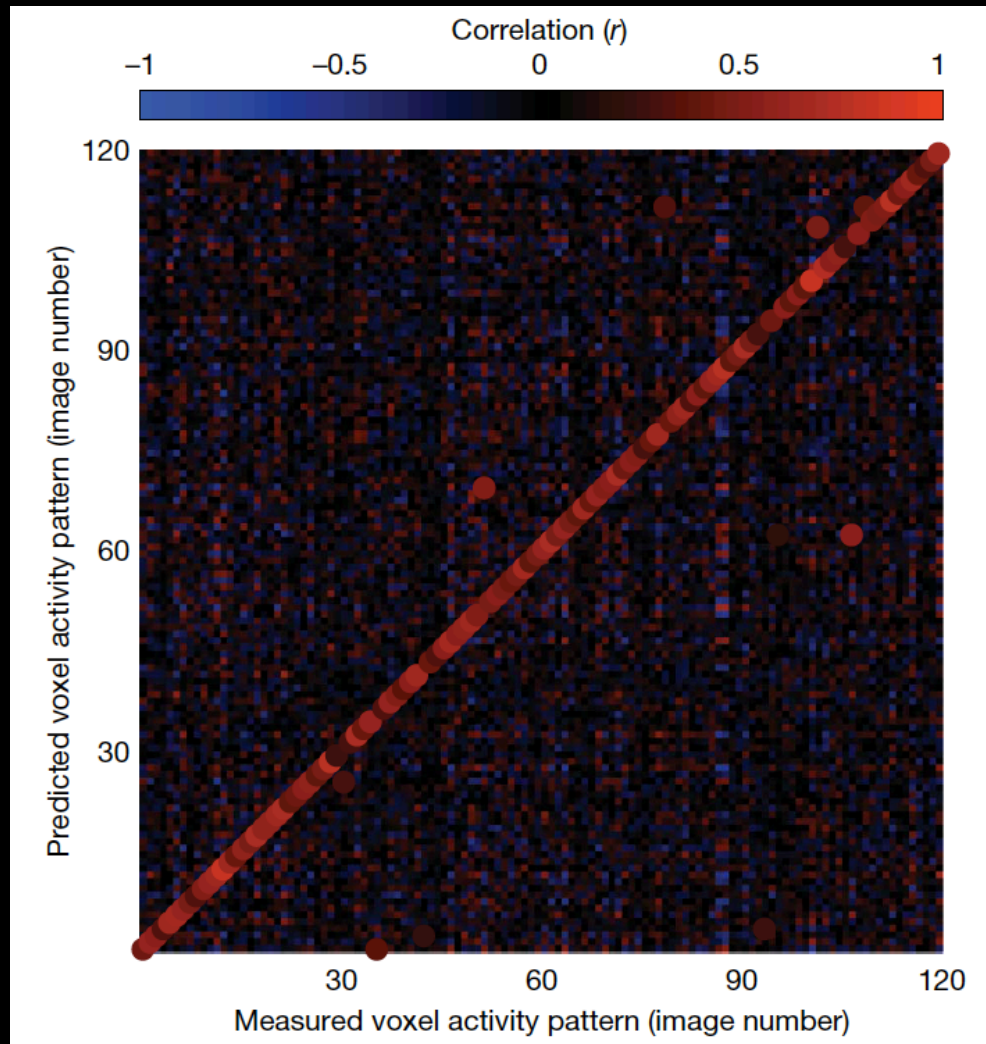
Compare observed to predicted activity

(2) Predict brain activity for a set of images using receptive-field models



(3) Select the image (★) whose predicted brain activity is most similar to the measured brain activity

Performance



Additional results

- Works on single trials
- Not just retinotopy
- Accurate even with long delay between model fitting and testing

Limitations of Kay et al.

- Still requires comparison with set of candidate images
- Will likely fail with more homogeneous images (e.g. two faces)
- Whole image comparison
 - What about same central object on different backgrounds?
- How sensitive to fixation differences?
- Novel subjects?
- Visual perception is dynamic

Semantic space

- Huth et al (2012). A continuous semantic space describes the representation of thousands of object and action categories across the human brain. *Neuron*.
- <http://gallantlab.org/brainviewer/>

Visual Image Reconstruction

[Miyawaki et al (2008)]

- Model based decoding
- Characterize relationship between activity and contrast of local image patches
- Use activity to predict contrast within image

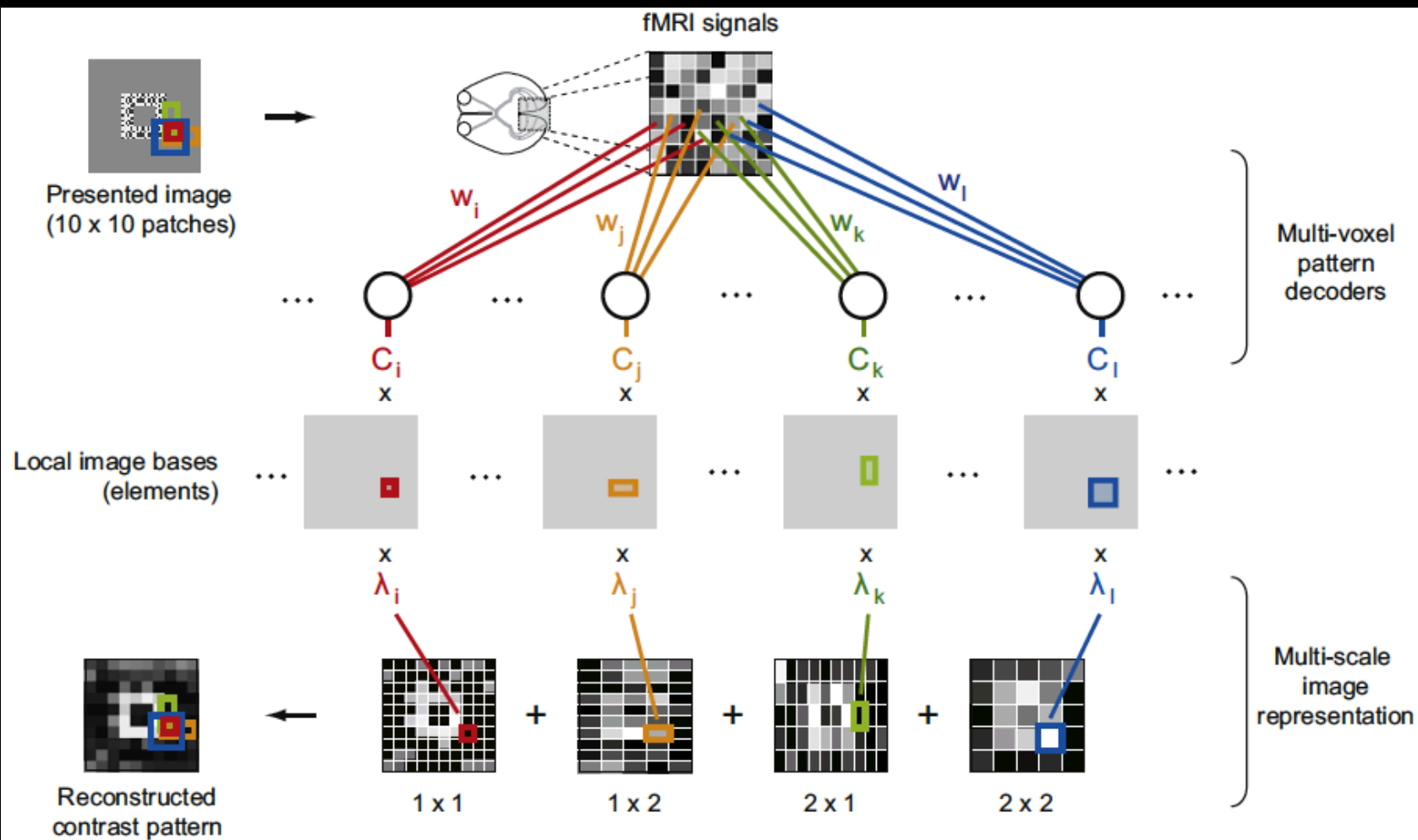
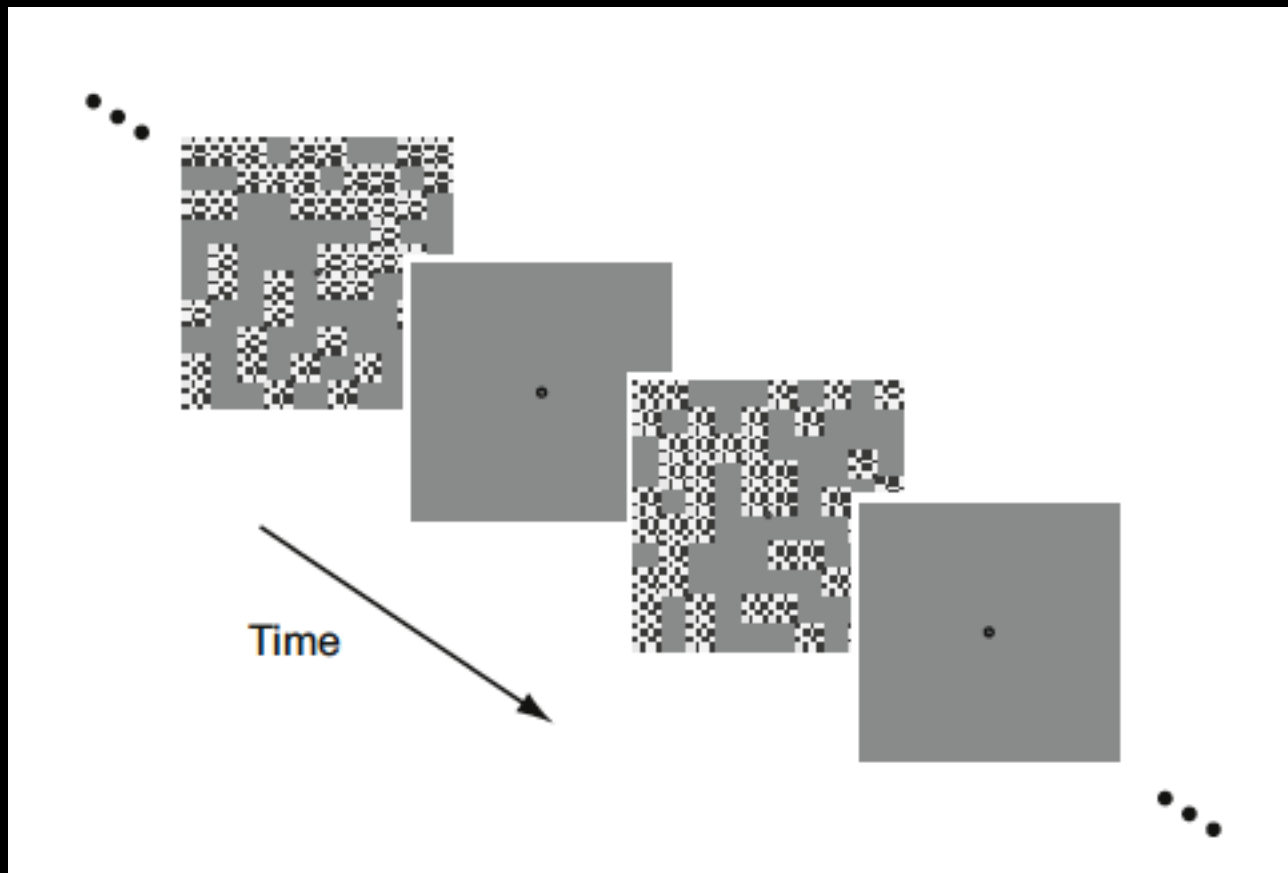
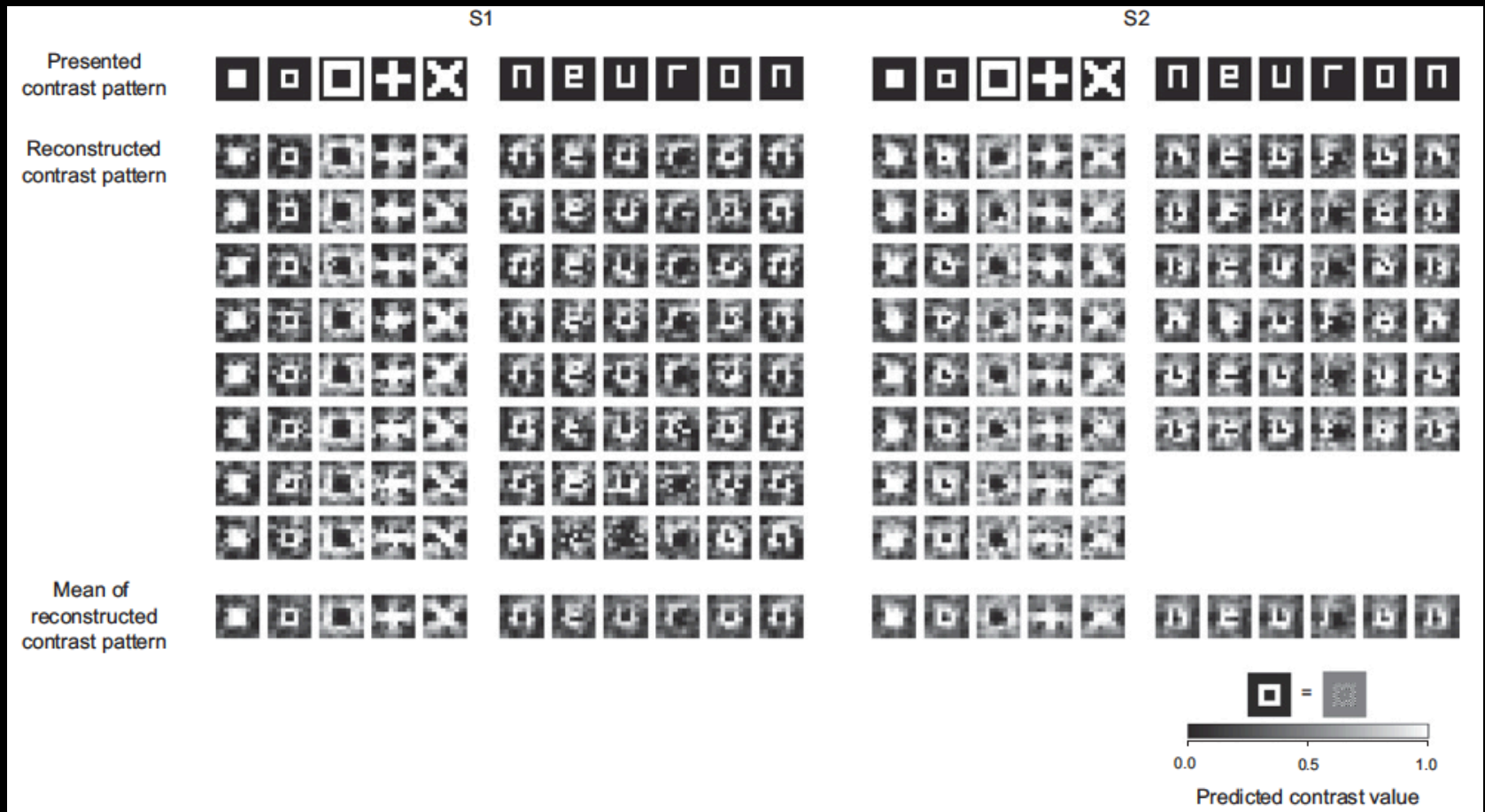


Image presentation



Reconstructions



Limitations of Miyawaki et al

- Similar limitations to Kay et al.
- Simple, non-natural stimuli
- Small image size

For extension of Kay et al. into reconstruction, see
Naselaris et al (2009)

Applications for fMRI brain reading

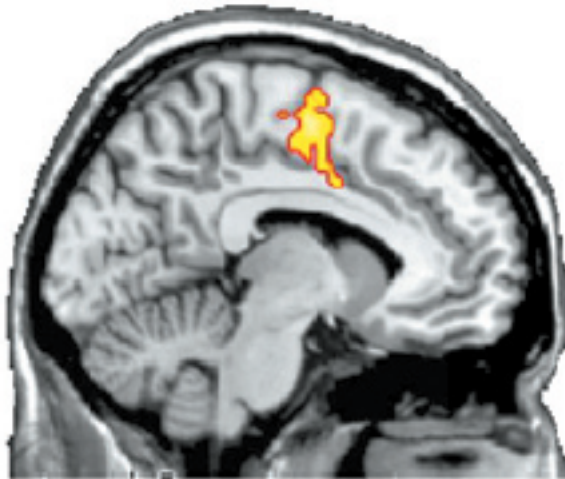
- 1) Understanding how information is represented in the brain
- 2) Lie detection?
- 3) Prosthetic devices?
- 4) Disorders of consciousness

Disorders of consciousness

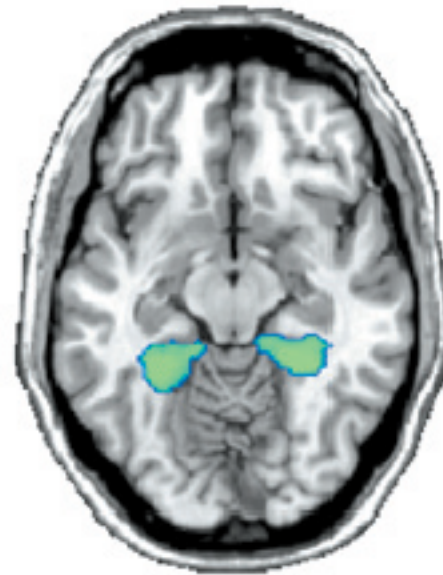
- Vegetative state
- Locked-in syndrome
- Enabling communication in the absence of overt motor behavior

Decoding Tasks

A Healthy Controls

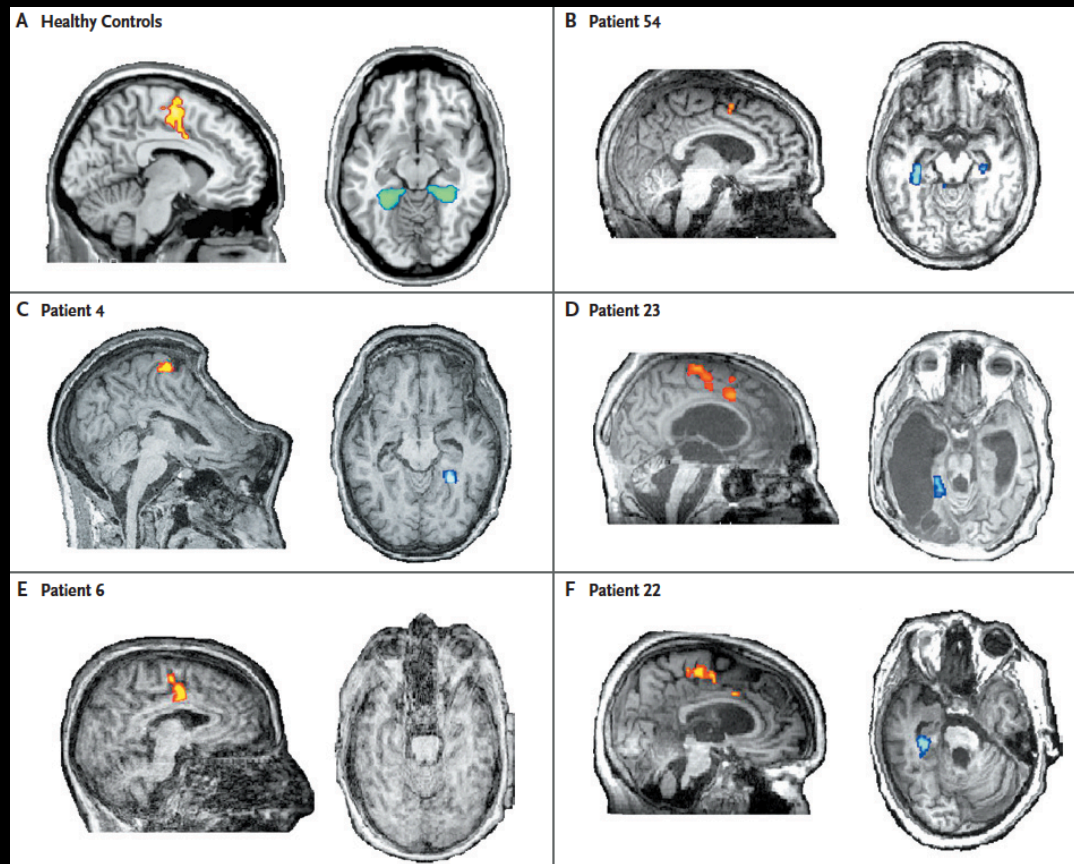


Motor Imagery
(playing tennis)

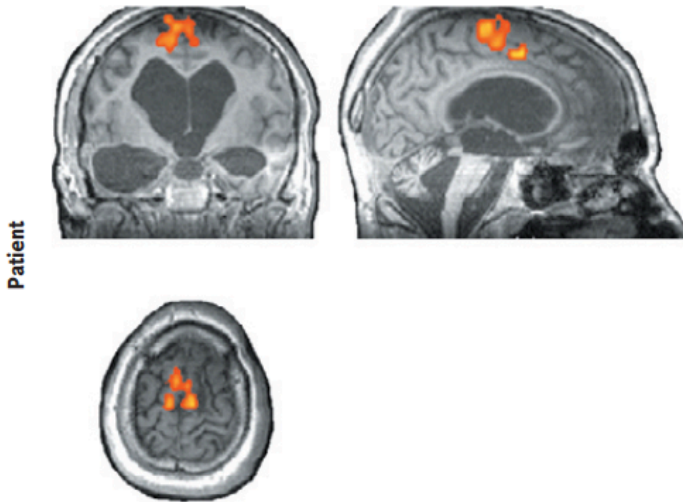


Spatial Imagery
(walking house)

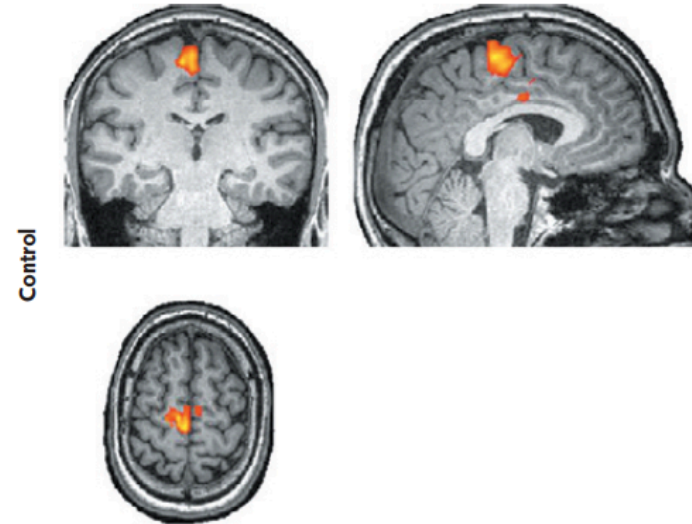
54 patients with severe brain injury



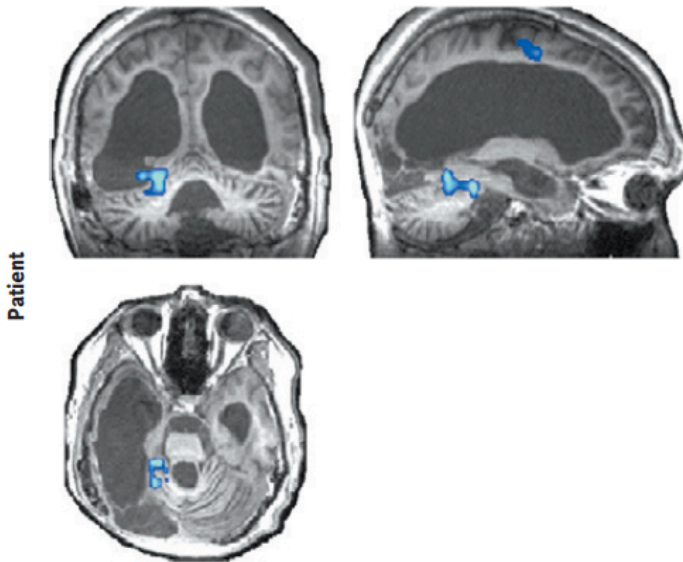
A "Is your father's name Alexander?" "Yes" response with the use of motor imagery



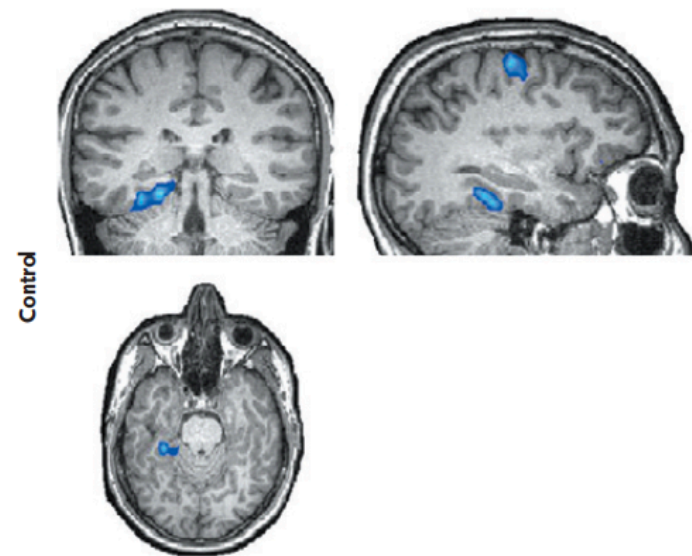
B "Do you have any brothers?" "Yes" response with the use of motor imagery




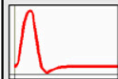
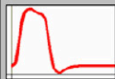

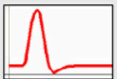


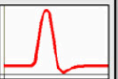
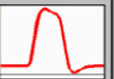



















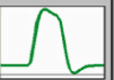

C "Is your father's name Thomas?" "No" response with the use of spatial imagery



D "Do you have any sisters?" "No" response with the use of spatial imagery



Real time fMRI spelling

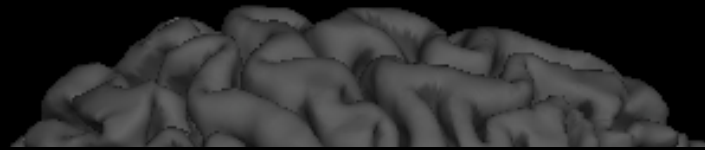
		TIMING								
Onset delay		0 s			10 s			20 s		
Duration		10 s	20 s	30 s	10 s	20 s	30 s	10 s	20 s	30 s
MENTAL TASK	motor imagery	-	A	B	C	D	E	F	G	H
	 ROIs									
	mental calculation	I	J	K	L	M	N	O	P	Q
	 ROIs									
	inner speech	R	S	T	U	V	W	X	Y	Z
	 ROIs									

Real time fMRI spelling

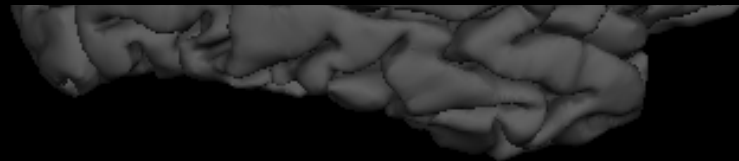
participant	initial question		follow-up question	
	stated question	decoder output/ human interpreter's decision	stated question	decoder output/ human interpreter's decision
1	"What is your hobby?"	P H O T O G R A P H Y - - Q G M X X E I C N G W R R N E P S V H S - Y Z X I I P H O T O G R A P H Y - -	"What did you PHOTOGRAPH last?"	- D Y - H O M E - R M W R Z M O G R A T Z S G V T W A - M Y - H O M E -
2	"Where did you spend your most recent vacation?"	- I N D O N E S I A - A F Q F M M G S I - A I R O B D O F J D C B - I N D O N E S I A -	"What did you like most in INDONESIA?"	- T E K P L E S - I R G M X U D J I A S D L Q M G R A - T E M P L E S -
3	"Where did you spend your most recent vacation?"	- I N D I A - S - E B - C A U A M E A B B - I N D I A -	"What do you consider most typical for INDIA?"	- C L O S H I N G - A A J X T G R M E A R O U P R E A V D R - C L O T H I N G -
4	"What is your hobby?"	- D R S C U S R R N G - R C I T U S U S I P E R A B - R S T R U F M F I - D I S C U S S I N G -	"What is your favorite DISCUSSION topic?"	- A W Y T H I N G - A - N Z S G R P E I B K P W V Z J W H A - A N Y T H I N G -
5	"What are you interested in?"	- X O V I D R A V M U R E S I M X W - N J - M O V I E S	"Which MOVIE did you watch last?"	T O P F U N - V X N N L M I U Y O G J P A T O P G U N -
6	"Where did you spend your most recent vacation?"	- - I I D - D E S T - I A V C A P C U U I A B C F B Y D R V A - B U D A P E S T -	"What did you like most in BUDAPEST?"	- S W N - E N F I I E - A U X L A G X E V D A J T Y M O F M G S C R - S Y N A G O G U E -

“mind reading”

“thought identification”



What can we really do?



“prediction”

“decoding”

Key Readings

Overviews and Methods

- Cox and Savoy (2003). Functional magnetic resonance imaging (fMRI) “brain reading”: detecting and classifying distributed patterns of fMRI activity in human visual cortex. *Neuroimage*, 19, 261-270.
- Mur et al. (2008). Revealing representational content with pattern information fMRI - an introductory guide. *Social Cognitive and Affective Neuroscience*, 4, 101-109.
- Norman et al. (2006). Beyond mind-reading: multi-voxel pattern analysis of fMRI data. *Trends in Cognitive Sciences*, 10, 424-430.
- Sorger et al. (2012). A real-time fMRI-based spelling device immediately enabling robust motor-independent communication. *Current Biology*, 22, 1333-1338.
- Naselaris et al (2011). Encoding and decoding in fMRI. *Neuroimage*, 56, 400-410.

Specific Studies

- Albers et al (2013). Shared representations for working memory and mental imagery in early visual cortex. *Current Biology*.
- Haxby et al. (2001). Distributed and overlapping representations of faces and objects in ventral temporal cortex. *Science*, 293, 2425-2430.
- Kamitani and Tong (2005). Decoding the visual and subjective contents of the human brain. *Nature Neuroscience*, 8, 679-685.
- Kay et al (2008). Identifying natural images from human brain activity. *Nature*, 452, 352-355.
- Kay and Gallant (2009). I can see what you see. *Nature Neuroscience*, 12, 245-246.
- Miyawaki et al (2008). Visual image reconstruction from human brain activity using a combination of multiscale local image decoders. *Neuron*, 60, 915-929.
- Nishimoto et al. (2011). Reconstructing visual experiences from brain activity evoked by natural movies. *Current Biology*, 21, 1641-1646.

Disorders of Consciousness

- Monti et al. (2010). Willful modulation of brain activity in disorders of consciousness. *New England Journal of Medicine*, 362, 579-589.
- Owen et al. (2006). Detecting awareness in the vegetative state. *Science*, 313, 1402

Resources

- SVM toolbox
 - <http://www.csie.ntu.edu.tw/~cjlin/libsvm/>
- Python MVPA toolbox
 - <http://www.pymvpa.org/>
- Princeton MVPA toolbox
 - <http://code.google.com/p/princeton-mvpa-toolbox/>

